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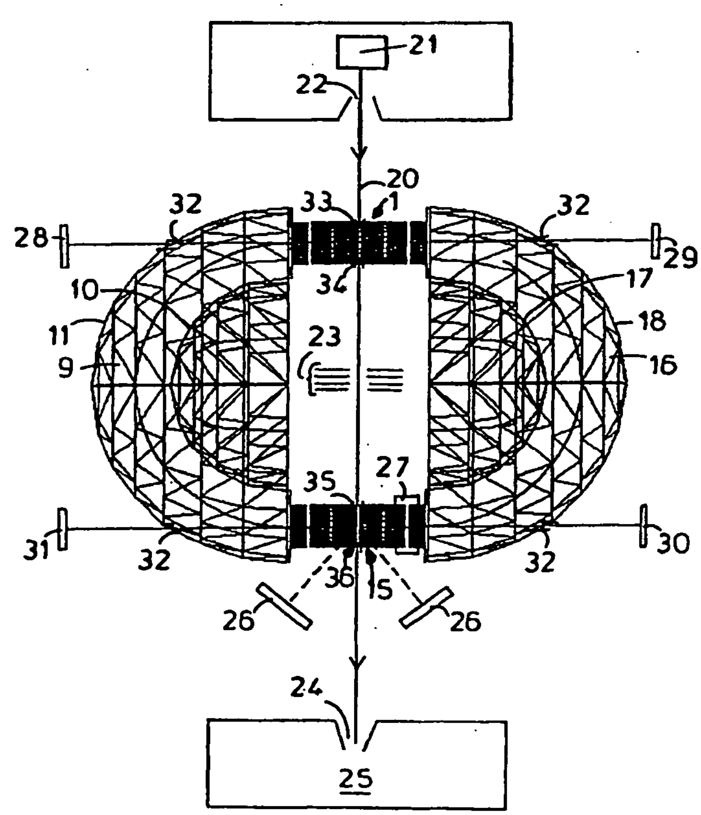
(54) Title: CHARGED PARTICLE BEAM GENERATOR

(57) Abstract

A charged particle beam generator comprising a source of charged particles located within a chamber which is arranged such that in use charged particles produced by the source are delivered to a closed loop beam path around which the charged particles are circulated, the beam path passing through the source of charged particles, the charged particles being confined to the beam path by an electrostatic field.



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CHARGED PARTICLE BEAM GENERATOR

The present invention relates to a charged particle beam generator, and particularly though not exclusively to an electron beam generator suitable for use as an electron spectrometer.

Electron spectrometers are commonly used to measure properties of gas beam targets. The properties may be measured in a variety of ways, for example an electron beam may be arranged to scatter elastically from a gas beam target, and the angles of scattering measured. Alternatively, a beam of electrons may be used to deflect and excite a gas beam, with the excited and deflected atoms being detected. In a further alternative, an electron beam may be arranged to scatter inelastically from a gas beam target, and the amount of energy lost or gained by the electrons determined.

In general, the resolution of measurements obtained using electron spectrometers is limited by the accuracy with which the energy of the incident electrons may be defined. Spectrometers having overall energy resolutions of 15 meV have been available since the 1970's. A number of attempts have been made to improve energy resolution to 1 meV. These attempts have involved replacing conventional thermonic electron sources, with sources which generate incident electrons from laser illumination of an atomic target, or with synchrotron radiation based electron sources.

A laser based electron source uses a narrow linewidth laser to cause photoionisation of an atomic target. The resulting photoelectrons are accelerated into a beam by an extraction potential for subsequent experimentation. The number of electrons produced in this way is sufficient for elastic electron scattering or elastic beam scattering experiments, but is not currently sufficient to allow inelastic scattering measurements (inelastic scattering measurements in general require large numbers of electrons). The energy resolution of the electrons produced by photoionisation reduces as the rate of electron production is increased. This is because the production of a current of electrons from an atomic surface by

photoionisation concurrently causes the production of an exactly similar ion current. The produced ions move very slowly and cause a charge density in the region where the laser beam interacts with the atomic target, which becomes significant when the electron production rate goes above $\sim 10^7$ per second (equivalent to 10^{-12} Amps). This concentration of ionic charge, known as a space charge, not only alters the local potential of the interaction volume, but also make it non-uniform. Electrons subsequently produced by photoionisation have different start potentials, which depend on the spatial position of production. The electron beam produced by photoionisation therefore has an energy width that is broadened by the effect of the space charge, and does not reflect the narrow linewidth of the laser causing the photoionisation. Thus, where it has been attempted to increase the rate of electron production, in order to perform inelastic gas phase scattering experiments, the energy resolution of the generated electrons is diminished. A further disadvantage of laser photoionisation is that lasers having the narrow linewidth required for photoionisation are expensive, and a series of lasers may be required to provide sufficient energy to excite atoms to ionisation.

In the field of surface science instruments, high resolution electron energy loss scattering has been achieved at energy resolutions in the region of 0.5 meV (H. Ibach, Electron Energy Loss Spectrometers, Springer-Verlag, 1991). In this instance electrons are produced in a conventional thermonic manner and are energy selected using conventional electrostatic dispersive elements. This arrangement suffers from the disadvantage that it generates only a few electrons, with electron currents in the region of 10^{-12} Amps. This number of electrons is not sufficient to allow measurement of properties of gas beam targets.

In the field of high energy physics, synchrotrons are used to generate bunches of very high energy electrons. The electrons are injected into a synchrotron from a linear accelerator and are confined in a circular or substantially circular path by a magnetic field which is applied perpendicular to the plane of the electron path. The high energy bunches of electrons are used for a variety of high energy experiments, for example for the generation of X-rays. The accuracy to which the energy of the

accelerated electrons may be defined is not a significant issue in high energy physics experiments, and consequently the accelerated electrons have a significant width of energies.

It is an object of the present invention to provide a charged particle beam generator which overcomes or mitigates the above disadvantages.

According to the invention there is provided a charged particle beam generator comprising a source of charged particles located within a chamber which is arranged such that in use charged particles produced by the source are delivered to a closed loop beam path around which the charged particles are circulated, the beam path passing through the source of charged particles, the charged particles being confined to the beam path by an electrostatic field.

The invention provides a beam of charged particles with high energy resolution. The high energy resolution stems from the combination of the electrostatic field and the circulation of the charged particles around the closed loop beam path. Those charged particles which do not have the specific energy required to follow the closed loop beam path will decay from the path, thereby leaving only charged particles of the desired energy in the closed loop beam path (i.e. a high energy resolution beam). The passage of the closed loop beam path through the source is advantageous because it allows the simple and efficient generation of a continuous beam of charged particles, the charged particles being added to the beam as and when they are generated.

The invention includes an arrangement wherein the source is provided in a potential well. Where this is done, particles are accelerated out of the source onto the beam path, and upon returning to the source have a high probability of being reflected from the source. Thus, the particles oscillate along the closed beam path between opposite ends of the source.

The invention uses electrostatic fields to confine the charged particles to the beam path, rather than a magnetic field as is conventionally used in prior art electron sources. Magnetic field confinement is conventionally used because it is relatively easily achieved for high kinetic energy charged particles.

A principle advantage of the electrostatic field over a magnetic field is that it may be controlled more easily than the magnetic field. Specifically, an electrostatic field may be more easily spatially localised since it can be screened efficiently using a non-magnetic conducting metal, whereas screening of a magnetic field is significantly more difficult, and requires complex and expensive screening devices. Due to the use of the electrostatic field, the apparatus according to the invention is capable of providing a beam of charged particles with a required energy resolution, more easily and with equipment that is smaller and cheaper than prior art equipment.

A further difference between the electrostatic field used by the invention and a magnetic field, as used by the prior art, is that force exerted on a charged particle is independent of the velocity of the charged particle. Therefore, a beam of charged particles having a non-heterogeneous speed is typically more difficult to control using a magnetic field than an electrostatic field. Using an electrostatic field, charged particles may be circulated around the closed loop beam path with a low energy (by establishing a weak electrostatic field), or may be circulated with a high energy (by establishing a strong electrostatic field). Circulation in a closed loop beam path with low energy will provide a charged particle beam with good energy resolution, since a charged particle having an energy other than that required to follow the closed loop beam path will quickly decay from that path. Circulation in a closed loop beam path with high energy will provide less good energy resolution. Thus, a required energy resolution may be selected by adjusting the energy of the charged particles circulating around the closed loop beam path when using an energetically broad particle source.

GB995563 describes a synchrotron accelerator which is used to generate a high energy ion beam. The synchrotron accelerator comprises a positive ion gun located within a doughnut-shaped structure. Ions pass through the ion gun in a closed

loop beam path, and are accelerated to a high energy by the synchrotron. The synchrotron uses a magnetic field to confine the ions to the closed loop beam path, and therefore does not provide energy resolution selection, as is provided by the invention.

Preferably, the generator according to the invention is arranged to generate charged particles having an energy of less than 100eV, and most preferably charged particles having an energy of less than 10eV.

GB995563 does not describe the generation of a high resolution beam of low energy charged particles. Furthermore, to generate a beam of low energy charged particles, as is provided by the invention, the intensity of the magnetic field that would be required for the apparatus described in GB995563 is so weak that residual magnetism of the components of the synchrotron accelerator would have a disruptive effect on the beam path, thereby compromising the energy resolution and stability of the charged particle beam.

Preferably, the chamber comprises first and second cavities each defined by substantially hemispherical inner and outer walls. A radial electrostatic field is established between the inner and outer walls. Other alternative cavity geometries, for example 90 degree deflectors separated by straight legs, will be apparent to those skilled in the art. The hemispherical cavities are preferred because the required electrostatic field arises naturally from the shape of the inner and outer walls, and provides focussing in two dimensions.

Preferably, the source of charged particles comprises a charged particle production region located between two lenses. The charged particle production region may be field free. The field free production region is useful when charged particles are produced with some kinetic energy. Where charged particles are produced with little or no kinetic energy, a field will be required in the charged particle production region to draw the charged particles from that region.

Preferably, the first and second cavities are spaced apart, and the charged particle production region is located between the first and second cavities. The inventor has realised that by coupling two hemispherical radial fields by two straight lens stacks, a stable closed loop charged particle beam path may be established.

The lenses may be two element lenses, with the charged particle production region located within an inner element common to both lenses. Alternatively, the lenses may be three element lenses. The three element lenses may provide a better quality charged particle beam. The ratio of the lens diameter to the distance by which the first and second cavities are spaced apart has a strong influence on the stability of the closed loop beam path. For example, a ratio of the order 0.5 or less, has been found to lead to good stability.

Preferably, two further lenses, spaced away from the source, are located between the first and second cavities. The two further lenses may be used to accelerate or decelerate the charged particles, such that the speed of the charged particles between the two further lenses is independent of the speed of the charged particles in the first and second cavities. The two further lenses may be two element lenses, or may be three element lenses.

Preferably, the first and second cavities are each provided with at least one termination. However, the charged particle beam generator may not require terminations, and may operate in a stable manner without them.

For a pre-selected direction of charged particle trajectory, terminations may be provided at entrances of the first and second cavities, with no terminations provided at exits of the first and second cavities. This arrangement is advantageous because it allows charged particles to travel in a well-defined trajectory in the pre-selected direction, but inhibits charged particles from travelling in the opposite direction. A weak magnetic field applied across the system may be used as an alternative to the selectively positioned terminations, to pre-select the direction of charged particle travel.

Preferably, the charged particle generator is an electron generator. The electron generator may comprise part of an electron gun or electron spectrometer, and may be provided with an electron scattering region located between the first and second cavities. The electron scattering region is preferably located between the two further lenses.

The invention, when used as an electron spectrometer makes use of the fact that the probability of scattering an electron in a gas beam is very low (the effective area of an atom from an electron scattering point of view is roughly 10^{-16} cm^2). Thus the vast majority of electrons in an electron beam passing through a gas beam will not interact with atoms in the gas beam at all. In the present invention, electrons passing through a target gas beam are collected, sent around a cavity, re-passed through the electron source, passed around another cavity and given another chance to interact with the target gas beam. This process will repeat indefinitely, unless the electron is scattered in the target gas beam, or interacts with a background gas atom. The invention thus significantly reduces the rate of electron production required in order to observe inelastic scattering from a target gas beam. Where electron production is by photoionisation, the low rate of electron production avoids the ionic space charge build up which is seen in laser photoionisation electron sources.

A further advantage of the invention is that the charged particle scattering region is substantially free of magnetic fields which may distort scattering measurements.

The charged particle beam generator may be arranged to act as a source of charged particles, and may be provided with means for directing charged particles out of the generator.

Preferably, the directing means are conducting plates.

Preferably, a side wall of the charged particle beam generator is provided with a hole through which charged particles may be directed out of the generator. The hole is preferably a slot. The use of a hole in the side wall is preferred over the provision of a mesh to allow coupling from the generator because the locations of holes in a mesh will not be known accurately, and a proportion of charged particles will interact with the mesh and cause scattering and energy loss.

Production of charged particles in the charged particle production region may be achieved by directing a beam of charged particles or a laser at a spatially defused gaseous target. The target is preferably a supersonic gas beam. Alternatively, electrons may be produced via the ejection of electrons from atoms excited by collision, or using a thermonic element.

Preferably, the charged particle beam generator is located in a magnetic field free environment. This environment may be provided using Helmholtz coils to cancel the Earth's magnetic field and/or by surrounding the generator with mu-metal which provides magnetic field screening. The generator may function correctly in a weak magnetic field, provided that the generator is correctly oriented in relation to the magnetic field.

A specific embodiment of the invention will now be described by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic three dimensional representation of a charged particle beam generator according to the invention;

Figure 2 is a schematic two dimensional representation of the charged particle beam generator shown in Figure 1;

Figure 3 is schematic perspective cross-section of the charged particle beam accelerator shown in Figure 1;

Figure 4 is a schematic perspective cross-section of a charged particle production region comprising part of the charged particle beam accelerator shown in Figure 1; and

Figure 5 is a schematic representation of the charged particle beam accelerator shown in Figure 1, showing electron production and scattering means.

Electrons are produced in a field free production region 1 (the term field free is intended to mean that little or no electric field is present). The production region 1 is shown in cross-section in Figure 3 and is shown in detail in Figure 4. The production region 1 is defined by a cylindrical wall 2, and by plates 3 which shield the region 1 from external electric fields. Electrons may be produced in the production region 1 by a variety of different mechanisms, which are discussed below.

Electrons produced in the production region 1 pass through small holes 4 (of the order of 1 mm in diameter) in the plates 3 into a simple two element lens, which comprises inner and outer elements 2,5 spaced apart by gaps 6. The inner element 2 comprises the cylindrical wall 2. The inner and outer elements 2,5 are held at different potentials which, together with the size of the gap 6, determines the focussing effect of the lens. In this case the inner element 2 is held at 1 V and the outer element 5 is held at 10 V. Further plates 7 are located at outer ends of the outer elements 5. These plates 7 are also provided with small holes 8 to allow the passage of electrons.

Referring now to Figure 2 in addition to Figures 3 and 4, electrons passing in an anti-clockwise direction through the outer element 5 of the lens enter a left hand hemisphere 9 of the beam generator, defined by an inner wall 10 and an outer wall 11. The inner wall 10 and outer wall 11 of the left hand hemisphere 9 are held respectively at 16.7 Volts and 6.0 Volts such that a radial electric field is defined across the left hemisphere 9, the field having a path through the left hemisphere 9 with a potential of 10 Volts. The pass energy of the left hemisphere 9 is thus 10 eV.

On exiting the left hemisphere 9 the electrons pass through a second lens comprising inner and outer elements 12,13 spaced apart by a gap 14. The electrons are decelerated by the second lens to 1 eV, and enter an electron scattering region 15. The electron scattering region has the same structure as the electron production region 1, and is well shielded from electric fields. The difference between the potentials of the first inner lens element 2 and the second inner lens element 12 determines the energy of the electrons delivered to the electron scattering region 15. It is in the electron scattering region 15 that electron spectroscopy experiments are carried out. These experiments may comprise for example, scattering the electrons elastically from a gas beam target and measuring the angles of scattering, deflecting and exciting a gas beam to detect the excited and deflected atoms, or scattering the electrons inelastically from a gas beam target and measuring the amount of energy lost or gained by the electrons.

The majority of electrons will be unaffected by passage through the scattering region 15. On leaving the electron scattering region 15 the electrons pass through the outer element 13 of the second lens, whereupon they are again accelerated to 10 eV, and pass around a right hand hemisphere 16 of the beam generator, defined by an inner wall 17 and an outer wall 18. The inner wall 17 and outer wall 18 are held at 16.7 Volts and 6 Volts respectively. On leaving the right hand hemisphere 16 the electrons are decelerated to 1 eV by the first lens (lens elements 2,5), and passed through the electron production region 1, from where they pass once again into the left hand hemisphere 9. Electrons having an energy other than 10 eV will not pass through the left hand and right hand hemispheres 9, 16, and will be lost from the electron beam. This provides the electron beam with high energy resolution, an effect which is enhanced by the continuous circulation of the electrons.

The energy resolution provided by the beam generator is determined by the pass energy of the hemispheres 9, 16. A low pass energy will provide good energy resolution, and a high pass energy will provide less good energy resolution. The pass energy is adjusted by changing the voltages applied to the inner 10, 17 and outer 11, 18 walls of the hemispheres 9, 16. The voltages applied to the lenses should be

anti-clockwise propagation of electrons. It is known that high quality electron orbits can be achieved in hemispheres when entrance field terminations are optimised, and that electron trajectories are little affected by the exit field terminations. Thus an electron propagating in an anti-clockwise direction in the illustrated beam generator will enter a high quality orbit, whereas an electron propagating in a clockwise direction will not enter a high quality orbit and will eventually decay out of that orbit. This hemisphere termination configuration may therefore provide the capability to achieve a single electron propagation direction. Jost correctors are preferred because they are easy to model and easy to make.

As an alternative to selective hemisphere termination, a weak magnetic field may be applied across the beam generator. The field may be arranged such that electrons propagating in an anti-clockwise direction have the right amount of curvature to continue propagation through the hemispheres 9,16, whereas electrons propagating in a clockwise direction will tend to curve in an outward direction and will not be able to continue propagation through the hemispheres 9,16. This arrangement is not preferred because it adds extra complication to the beam generator.

In a further alternative arrangement, the direction of electron propagation may be selected by applying two localised magnetic fields to the generator, to introduce two kinks into the orbit. The magnetic fields may be arranged such that the kinks are part of a high quality orbit for electrons propagating in an anti-clockwise direction, but are not part of a high quality orbit for electrons propagating in a clockwise direction.

The beam generator may be configured to favour the propagation of electrons in a clockwise direction rather than an anti-clockwise direction.

The electron production region 1 may be arranged as a potential well by setting the voltage at the production region 1 to a low value (for example zero Volts) and locating extra charged plates a few millimetres outside of the existing plates 3 (this arrangement is not shown in the Figures). A voltage of 5 V applied to the extra

correspondingly adjusted. It is noted that the energy of the electron beam at the production region 1 and at the electron scattering region 15 is independent of the pass energy of the hemispheres 9, 16.

The electrons will circulate until they undergo some kind of interaction in the electron scattering region 15 or elsewhere.

Field terminations may be provided at the entrance and exit of the left hand hemisphere 9 and the right hand hemisphere 16. Figures 3 and 4 show the locations of the field terminations 19. The illustrated field terminations 19 are based upon those described by Jost (J. Phys. E: Sci. Instrum., **Vol. 12**, 1979) and comprise flat corrector plates 19 located adjacent the entrance and exit of the left hand and right hand hemispheres. The field terminations act to bring the electric fields at the entrances and exits of the hemispheres 9,16 closer to a radial form. Other field termination formats known in the art may be used. However, Jost correctors are preferred since they are simple and require no additional voltages applied to them (an outer corrector plate 19 runs at 6.0 Volts, and an inner corrector plate 19 runs at 16.7 Volts).

The electron beam generator may produce and store electrons without the use of terminations. It may be preferred not to use terminations since this reduces the number of components comprising the generator, and thereby makes it easier and cheaper to manufacture.

One problem arising from the described embodiment of the invention is the capacity of the beam generator to allow counter propagating electron trajectories. This may be a significant difficulty if the number of electrons stored in the beam generator is sufficiently large (greater than for example 1000 electrons), such that counter propagating electrons may closely approach each other, thereby modifying their energies, reducing the energy resolution of the beam generator and adding an additional electron loss mechanism to the beam generator. To counter this problem field termination is provided only at the entrance end of each hemisphere 5,12, for

charged plates will cause a small amount of field penetration into the electron production region 1. The field will act to accelerate electrons out of the electron production region 1 and into one of the hemispheres 9, 16. On returning to the electron production region 1, the electrons will encounter a potential hill. A few electrons will climb the potential hill and pass through the electron production region 1, but the majority will be reflected back from the potential hill. In this manner the electrons will oscillate along a closed beam path.

Calculations made in respect of the beam generator shown in the Figures indicate that when a stable orbit is achieved, electrons on average manage about 10,000 orbits at a background gas pressure of 10^{-6} mbar in a 51.5 cm long orbit. The orbital time is about 270 ns. Thus one orbiting electron on average represents a "beam" current of 0.58 pA (dc equivalent storage period). For this "current" to be maintained as a "DC" current, storable electrons must be produced at about 376 per second, though the required total electron production rate is higher since many electrons will not enter the required orbit. If a "beam current" of 1 nA is required the minimum production rate is a factor of 1000/0.58 larger, i.e. 6.4×10^5. When the pressure in the beam generator is reduced to 5×10^{-9} mbar, the number of orbits is approximately 2×10^6 (i.e. a storage time of 0.6 s).

The method by which electrons are produced is an important element of the electron beam generator. Favoured methods utilise a supersonic beam of atoms arranged to pass through a production region 1 of the beam generator. Three possible methods involve the excitation of the supersonic beam of atoms using a laser.

In a first method the atoms are directed through the production region 1, where they are illuminated by a set of narrow line width lasers such that they are excited to an ionisation energy. This method typically requires four lasers in order to provide sufficient illumination to ionise the atoms.

In a second method, the atoms are pre-excited in a supersonic beam before entry into the production region 1. The atoms are pre-excited using electron beam

impact external to the production region 1 to metastable states (e.g. 2^3S and 2^1S in Helium). Once the atoms enter the production region 1, one or two photon ionisation via a narrow line width laser is used to generate electrons.

In a third method, the atoms are pre-excited as above, but to a higher excitation energy (a high principle quantum number Rydberg state). Once the atoms enter the production region 1, they are excited to ionisation using a long wavelength narrow line width laser.

The first and second methods require expensive lasers having relatively short wavelengths. In contrast to this, the third method uses a longer wavelength laser which is readily available in diode laser form. In order to pump atomic transitions in a reliable manner the laser diodes may need to be frequency locked. This may be done using etalons.

The third electron production method provides an electron beam with a Doppler limited energy width. Furthermore, the ion production rate and electron production rates are low, hence avoiding possible space charge problems. It has yet to be established either theoretically or experimentally what electron production rates can be achieved by the third production method. However it is known that continuous wave (CW) lasers operating on metastable atom beams can produce electron beam currents of up to 1 nA (Weber *et al*, Phys. Rev. Lett., 1999, Vol.82, pg.516). This is useful for the present beam generator since the electron production rates required by the invention are significantly less than 1nA.

As mentioned above, the energy of the electrons in the scattering region 15 can be varied by accurate definition of the potential difference between the production region 1 and the scattering region 15. Where laser photoelectron production is used, finer control of the electron energy may be obtained via control of the laser frequency.

Three further methods of electron production involve the interaction of a supersonic beam of atoms with a beam of electrons.

In a fourth method, the beam of electrons is scattered elastically from the beam of atoms in the production region 1. This method can produce an electron current of approximately 10^{-17} amps (approximately = 100 electrons per second) in the production region. Storage of this beam at a low background pressure results in an equivalent current of approximately 1 pA.

A fifth method of electron production utilises ejected electrons. For example, a group of neutral excited states exist in helium atoms, which lie about 35 eV above the ionisation potential of helium. These excited states have a strong tendency to autoionise, which is an electron ejection process. An incident electron excites a helium atom to one of the excited states, and scatters with a kinetic energy which is the difference between the initial kinetic energy of the electron and the energy of the excited state of the helium atom.. The energy of the ejected electron is the difference between the excited state energy and the ionisation potential. The energy width of the ejected electrons produced in this manner is determined primarily by the natural lifetime of the autoionising state (not by the energy width of the incident electron beam) and is therefore well defined. The autoionising electron production route enables the wide energy resolution of an incident electron beam to be converted into a narrow energy resolution ejected electron beam (and may generate electrons having energies spread over a width of 40 meV or less). The energy spread of the ejected electron beam is further narrowed by passage through the hemispheres 9,16 of the beam generator.

In a sixth method, electron ionisation may be used to generate low energy electrons.

Each of the fourth, fifth and sixth electron generation methods is relatively cheap to implement. The fourth and sixth of the methods produce electrons with energies spread over a broad range. In contrast, the electrons produced by the fifth method will have a narrow spread of energies. Where the energy of the produced

electrons is not well defined, electrons having a required energy are selected by passage through the hemispheres 9,16 of the beam generator.

The fourth method of electron production, (i.e. elastic scattering of electrons) is illustrated in Figure 5. A supersonic gas beam 20 is generated by directing gas from a high pressure gas source 21 through an aperture 22. The gas source is held at approximately 10^{-5} mbar. The gas beam is directed into an electron production region 1, via an aperture 33 approximately 2 mm in diameter, where it scatters with a perpendicular beam of electrons. The beam of electrons is not shown in Figure 5, but would be perpendicular to the plane of Figure 5. Electrons are scattered from the gas beam 20, and move from the electron production region 1 to the left and right hand hemispheres 9,16. The electrons are produced with a significant amount of energy, and the two part lens shown in Figure 1 to 4 (labelled 2,5) may not be needed to accelerate the electrons into the hemispheres 9,16 (this applies to other methods which produce electrons having significant energy). The gas beam 20 passes through an aperture 34 and through a series of charged plates 23 which are used to deflect any ions and electrons present out of the gas beam 20. The gas beam 20 then passes into an electron scattering region 15 via an aperture 35. Electrons from the left and right hand hemispheres 9,16 interact with the gas beam 20. The majority of the atoms in the gas beam 20 are not scattered, and pass directly through an aperture 36 and into a gas beam dump chamber, which is held at a pressure of approximately 10^{7}mbar. Gas beam atoms which are scattered by the electrons are incident on detectors 26. A further detector 27 is arranged to detect elastically scattered electrons moving out of the plane of the Figure.

The arrangement shown in Figure 5 may be used, with suitable modifications, to generate electrons using the above described fifth and sixth electron generation methods.

A set of four detectors 28 - 31 are arranged outside the beam generator. The detectors 28 – 31 lie on the axis of propagation of electrons through the production and scattering regions 1, 15. Apertures 32 are provided in the left and right

hemispheres 9, 16 such that, when no electric field is applied to the hemispheres 9, 16, electrons will be incident on the detectors 28 – 31. Specifically, when no electric field is applied to the hemispheres 9, 16, electron production may be monitored using detectors 28 and 29. The performance of the left hand hemisphere 9 may be monitored by applying required electric fields to that hemisphere 9 and applying no field to the right hand hemisphere 16, such that electrons propagating in the anti-clockwise direction will be incident on detector 30. An inverse arrangement can be used to monitor the performance of the right hand hemisphere 16.

When voltages are applied to both hemispheres 9, 16, the number of stored electrons may be established by pulsing electron production on and off, and during the off period switching one hemisphere off at set delays with respect to the production off time. Electrons may then be counted, using the detectors 28 – 31, as a function of the delay time to establish storage efficiency. The other detectors 26, 27 may also be monitored.

The gas beam 20 is chosen to be supersonic in order to regulate the properties of the beam 20. In particular, all of the atoms in a supersonic beam have the same velocity (and therefore the same Kinetic Energy), all of the atoms are in the same energy state (due to efficient mixing of the atoms in the beam), and all of the atoms travel in a well defined direction. Since the direction of the supersonic gas beam 20 is well defined, very small apertures 33, 34 (2mm diameter) may be used to allow the supersonic gas beam to enter and leave the electron production region 1. The small size of the apertures 33,34 allows the pressure inside the beam generator to be kept at a low level (approximately 10^{-9} mbar). Furthermore, since the direction of the supersonic gas beam 20 is well defined there are few stray atoms in the beam generator to increase the pressure.

If electrons are produced in the electron production region 1 with very little energy, an electric field may be required in the electron production region to draw the electrons towards the hemispheres 9, 16.

The invention may be used to provide electrons of well defined energy for use in surface science and electron microscopy applications. This may be done by pulsing the stored electron beam out of the beam generator, for example by replacing the electron scattering region 15 with an element lens provided with a slot (not shown), and using deflection plates (not shown) to switch electrons through the slot and out of the beam generator. The plates are preferably turned on for a length of time equivalent to the time taken for an electron to orbit the beam generator so that all of the electrons in the beam generator are switched through the slot. The pulses of electrons obtained in this way will be of the order of 250 ns long, depending on the size of the beam generator, and may be used to provide time resolved studies of surfaces. Other types of hole may be provided. A hole or slot is preferred to a mesh arrangement because a mesh may scatter some of the electrons out of the beam.

Where the invention is used to generate electrons which are coupled out of the beam generator, the beam generator may be constructed without using lenses, provided that electrons produced in the electron production region have a significant amount of energy. However, the use of lenses is preferred since it provides focussing of the beam.

Although the beam generator has been described in terms of electrons, it will be appreciated that beams of positively or negatively charged ions may be generated using the invention.

CLAIMS

1. A charged particle beam generator comprising a source of charged particles located within a chamber which is arranged such that in use charged particles produced by the source are delivered to a closed loop beam path around which the charged particles are circulated, the beam path passing through the source of charged particles, the charged particles being confined to the beam path by an electrostatic field.

2. A charged particle beam generator according to claim 1, wherein the generator is arranged such that particles oscillate along the closed beam path between opposite ends of the source.

3. A charged particle beam generator according to claim 1 or 2, wherein the generator is arranged to generate charged particles having an energy of less than 100 eV.

4. A charged particle beam generator according to claim 3, wherein the generator is arranged to generate charged particles having an energy of less than 10 eV.

5. A charged particle beam generator according to claim 1 or claim 2, wherein the chamber comprises first and second cavities each defined by substantially hemispherical inner and outer walls.

6. A charged particle beam generator according to claim 5, wherein in use a radial electrostatic field is established between the inner and outer walls.

7. A charged particle beam generator according to any preceding claim, wherein the source of charged particles comprises a charged particle production region located between two lenses.

8. A charged particle beam generator according to claim 7 as dependent upon claim 5 or claim 6, wherein the first and second cavities are spaced apart, and the charged particle production region is located between the first and second cavities.

9. A charged particle beam generator according to claim 7 or 8, wherein the lens is a two element lens, and the charged particle production region is located within an inner element of the lens.

10. A charged particle beam generator according to claim 7, 8 or 9, wherein two further lenses, spaced away from the source, are located between the first and second cavities.

11. A charged particle beam generator according to claim 8 or any claim dependent thereon, wherein the lens has a diameter which is less than half the distance by which the first and second cavities are spaced apart.

12. A charged particle beam generator according to any preceding claim, wherein the first and second cavities are each provided with at least one termination.

13. A charged particle beam generator according to claim 12, wherein, for a pre-selected direction of charged particle trajectory, the terminations are provided at entrances of the first and second cavities, and are not provided at exits of the first and second cavities.

14. A charged particle beam generator according to any of claims 1 to 11, wherein the beam generator is not provided with any terminations.

15. A charged particle beam generator according to any preceding claim, wherein the charged particle generator is an electron generator

16. A charged particle beam generator according to any preceding claim, wherein the generator comprises part of an electron spectrometer, and is provided with an electron scattering region located between the first and second cavities.

17. A charged particle beam generator according to any of claims 1 to 15, wherein the generator is arranged to act as a source of charged particles, and is provided with means for directing charged particles out of the generator.

18. A charged particle beam generator according to claim 17, wherein the directing means are conducting plates.

19. A charged particle beam generator according to claim 18, wherein a hole is provided around the conducting plates, and the conducting plates are arranged to deflect charged particles from the system through the hole.

20. A charged particle beam generator according to any preceding claim, wherein production of charged particles in the charged particle production region is achieved by directing a beam of photons at a spatially defused gaseous target.

21. A charged particle beam generator according to any preceding claim, wherein the charged particle beam generator is located in a magnetic field free environment.

22. A charged particle beam generator substantially as herein before described with reference to the accompanying drawings.

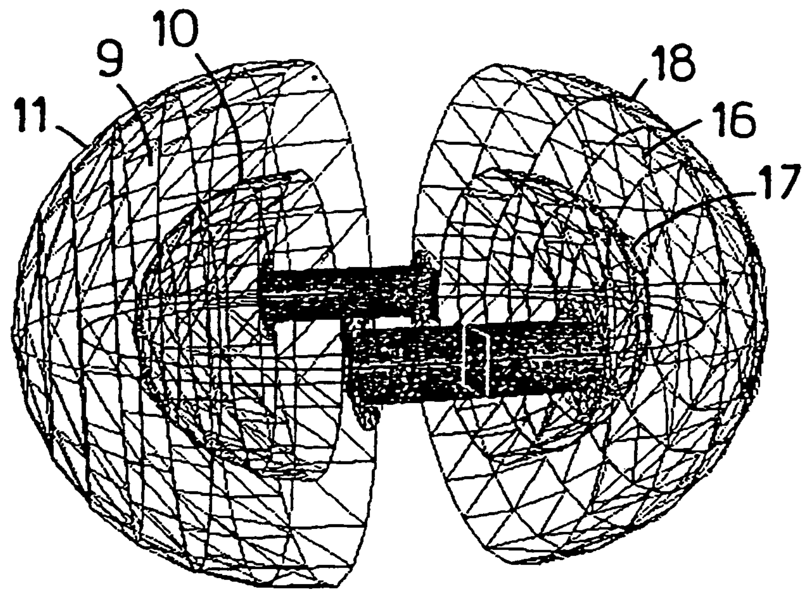

FIG. 1

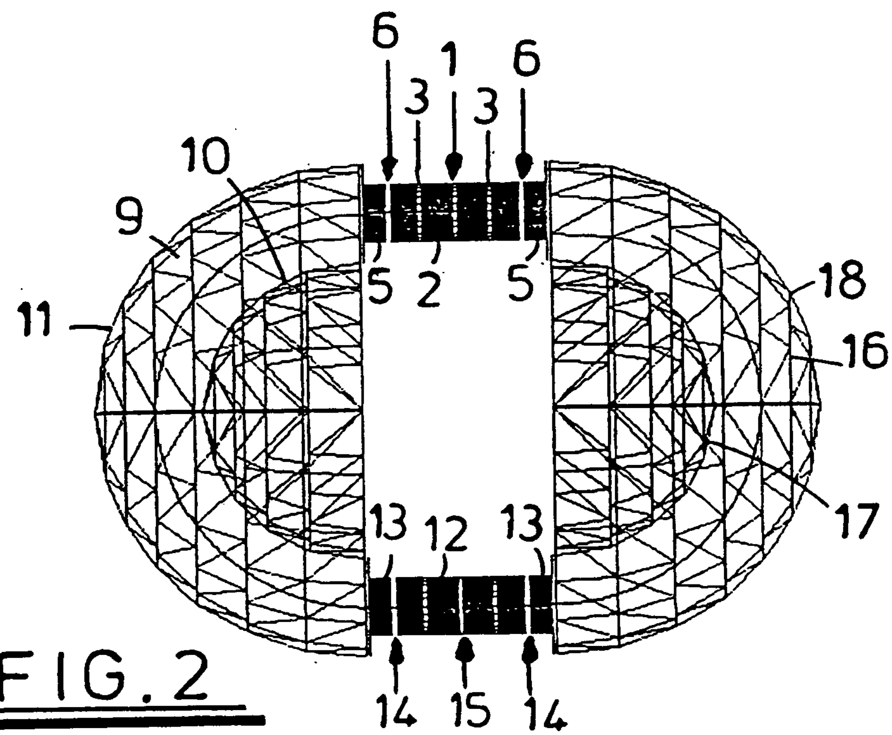

FIG. 2

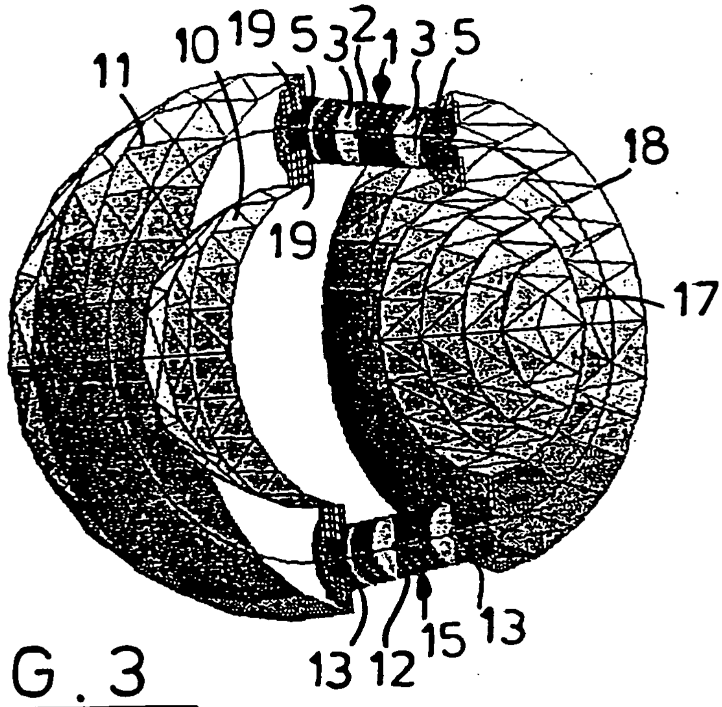

FIG. 3

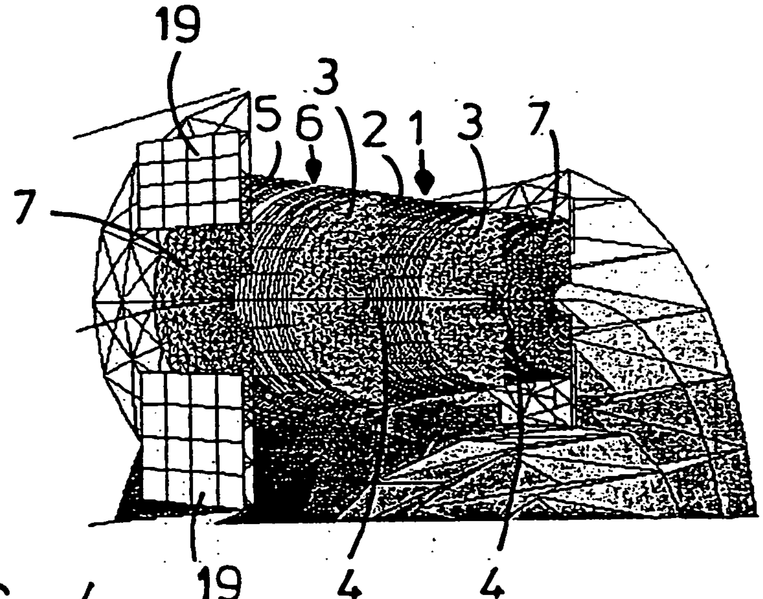

FIG. 4

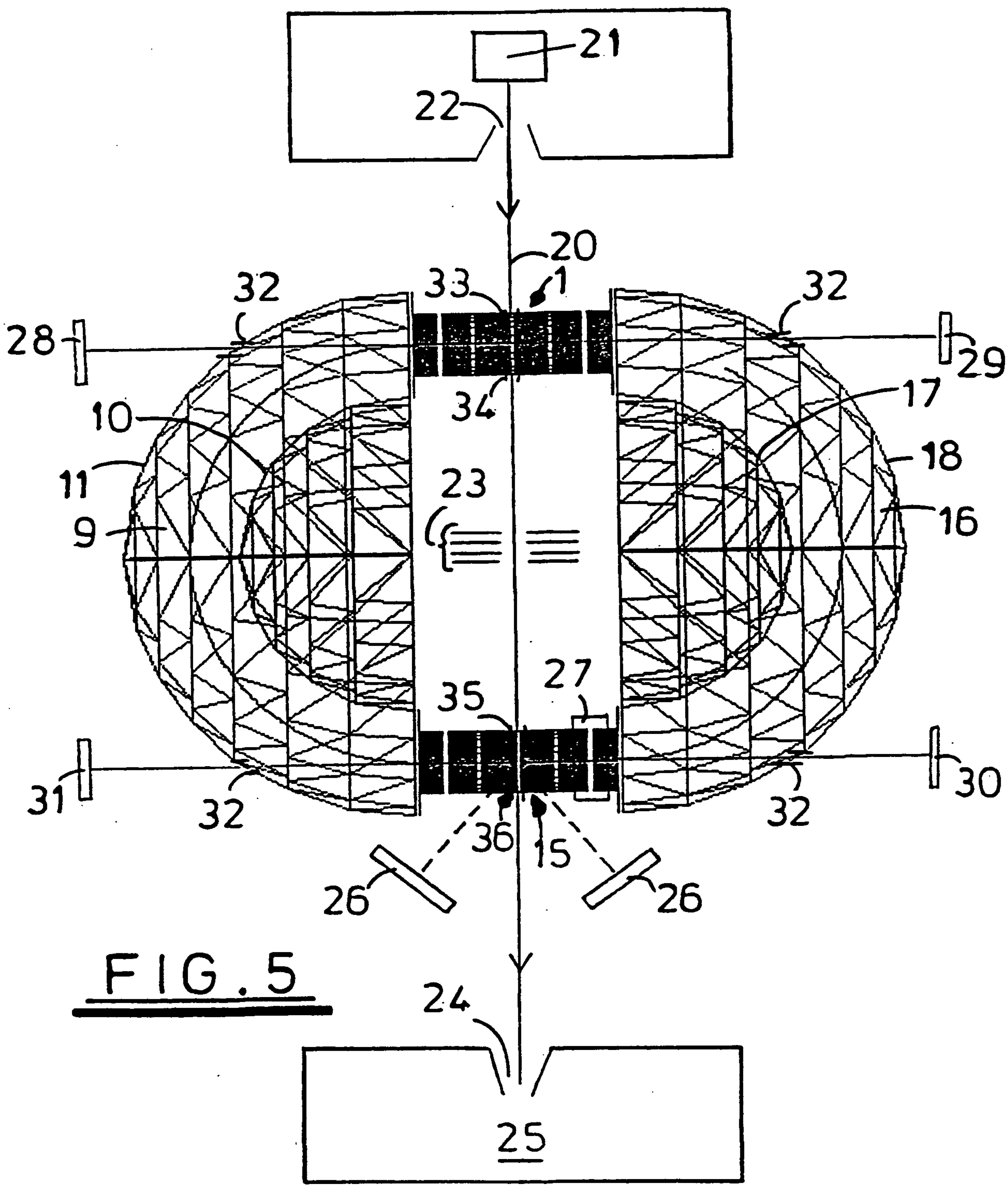
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FIG. 5

INTERNATIONAL SEARCH REPORT

Int. ional Application No
PCT/GB 00/00052

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01J49/48 H05H5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01J H05H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 995 563 A (VARIAN ASSOCIATES) cited in the application the whole document	1-22
A	CHEREPIN V: "SPHEROTRON - A NEW CONCEPT IN MASS SPECTROMETRY" INTERNATIONAL JOURNAL OF MASS SPECTROMETRY AND ION PROCESSES,NL,ELSEVIER SCIENTIFIC PUBLISHING CO. AMSTERDAM, vol. 121, no. 1 / 02, 26 November 1992 (1992-11-26), pages R01-R-10, XP000332110 the whole document	1
A	US 5 631 526 A (FERRY JAMES A) 20 May 1997 (1997-05-20) abstract	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" *document member of the same patent family*

Date of the actual completion of the international search	Date of mailing of the international search report
15 May 2000	22/05/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Zuccatti, S

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/00052

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 5631526 A	20-05-1997	NONE	